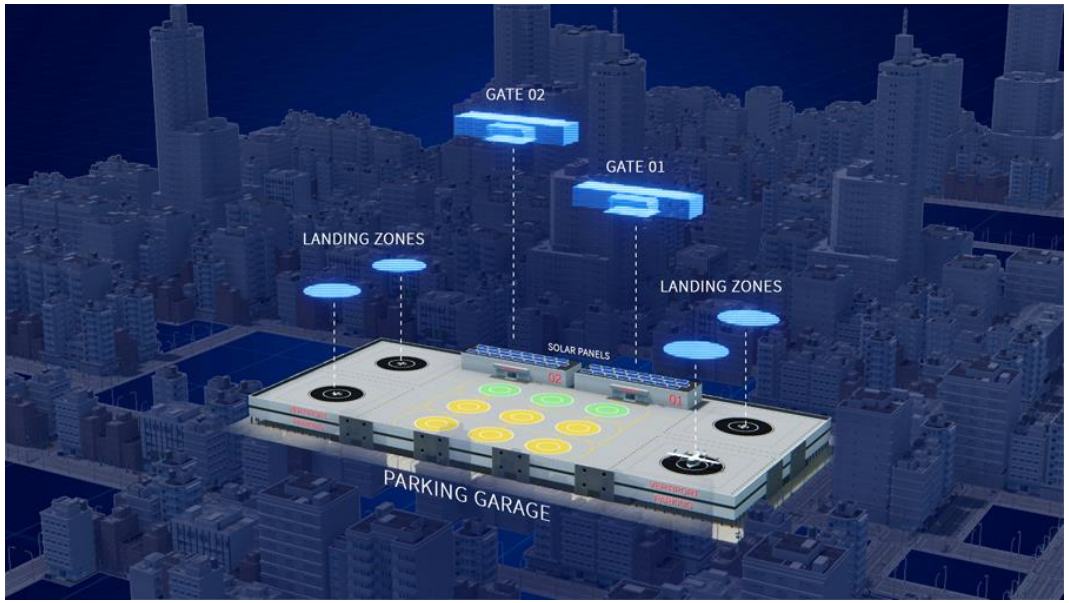
AAM PROJECT: HIGH DENSITY VERTIPLEX (HDV)

Research and Capabilities

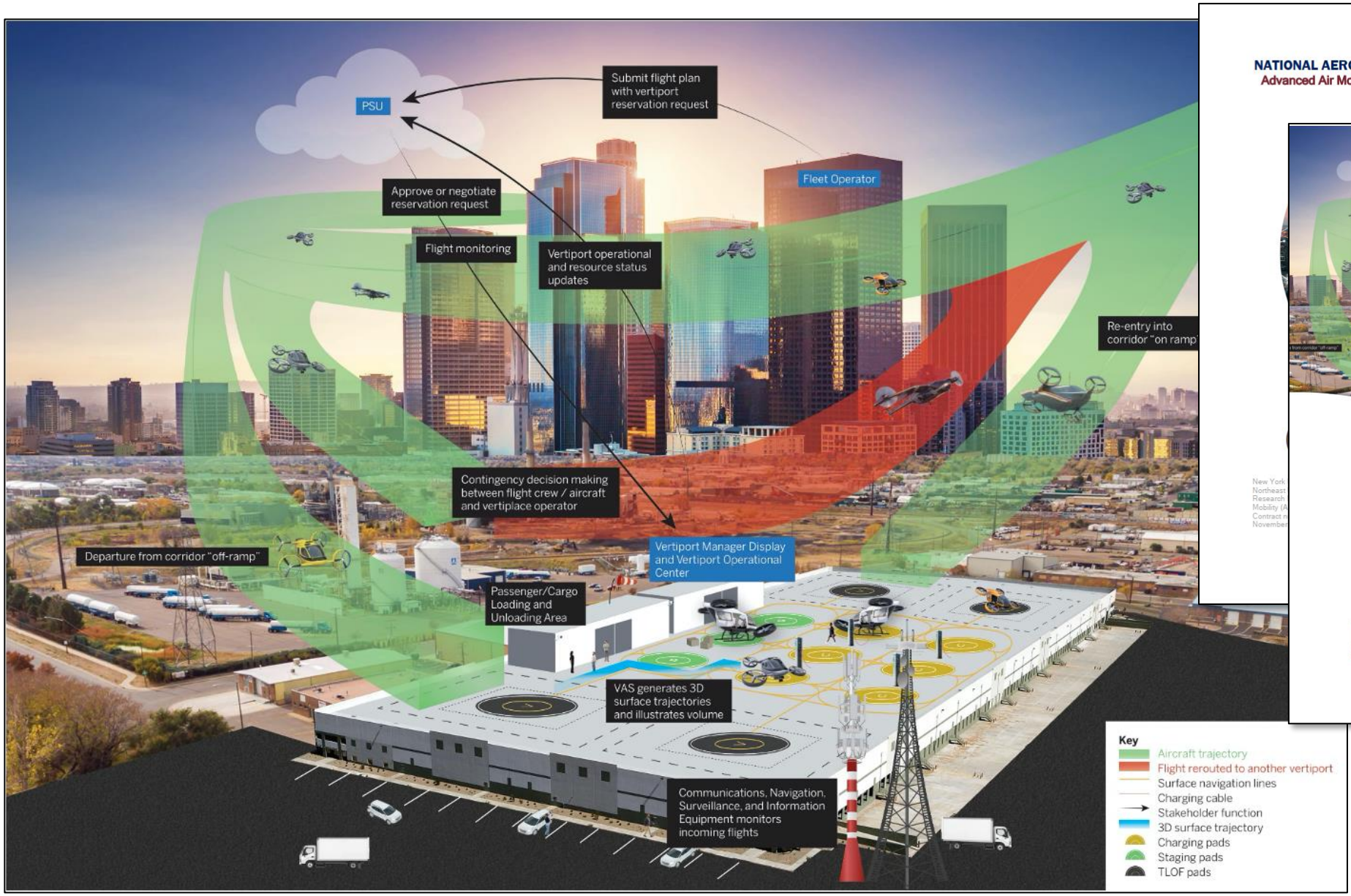
Jeffrey Homola
HDV Sub-Project Manager

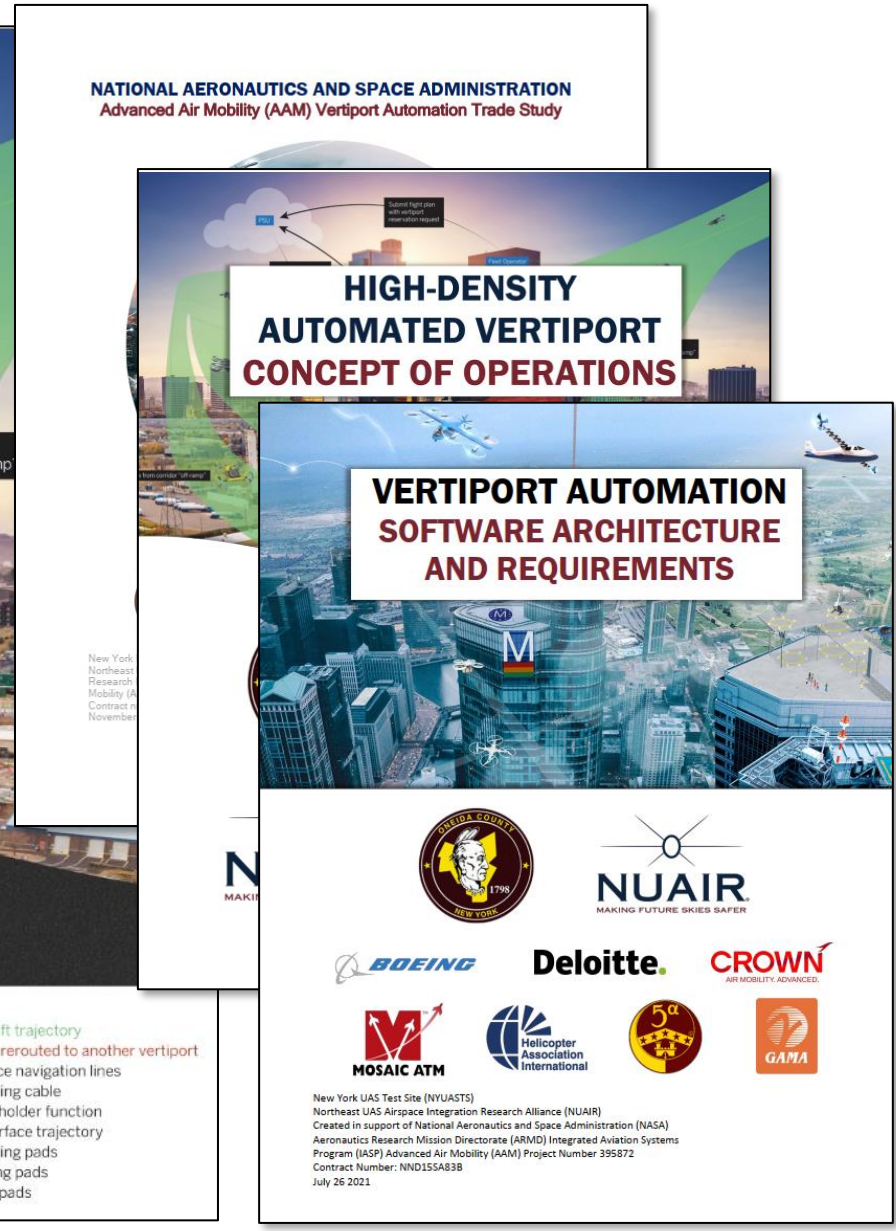
High Density Vertiplex Background



- Dedicated efforts initially underway on multiple fronts in the UAM/AAM domain
- Vertiport operations management identified as a key area to direct a focused research effort
- Need for research directed toward the systems, automation, roles, procedures, data exchanges, etc. associated with vertiport operations as an enabler for scalability, resilience, situation awareness, and efficiency
- High Density Vertiplex (HDV) Sub-Project established under the AAM Project

High Density Vertiport Operations Concept





High Density Vertiport Operations Concept

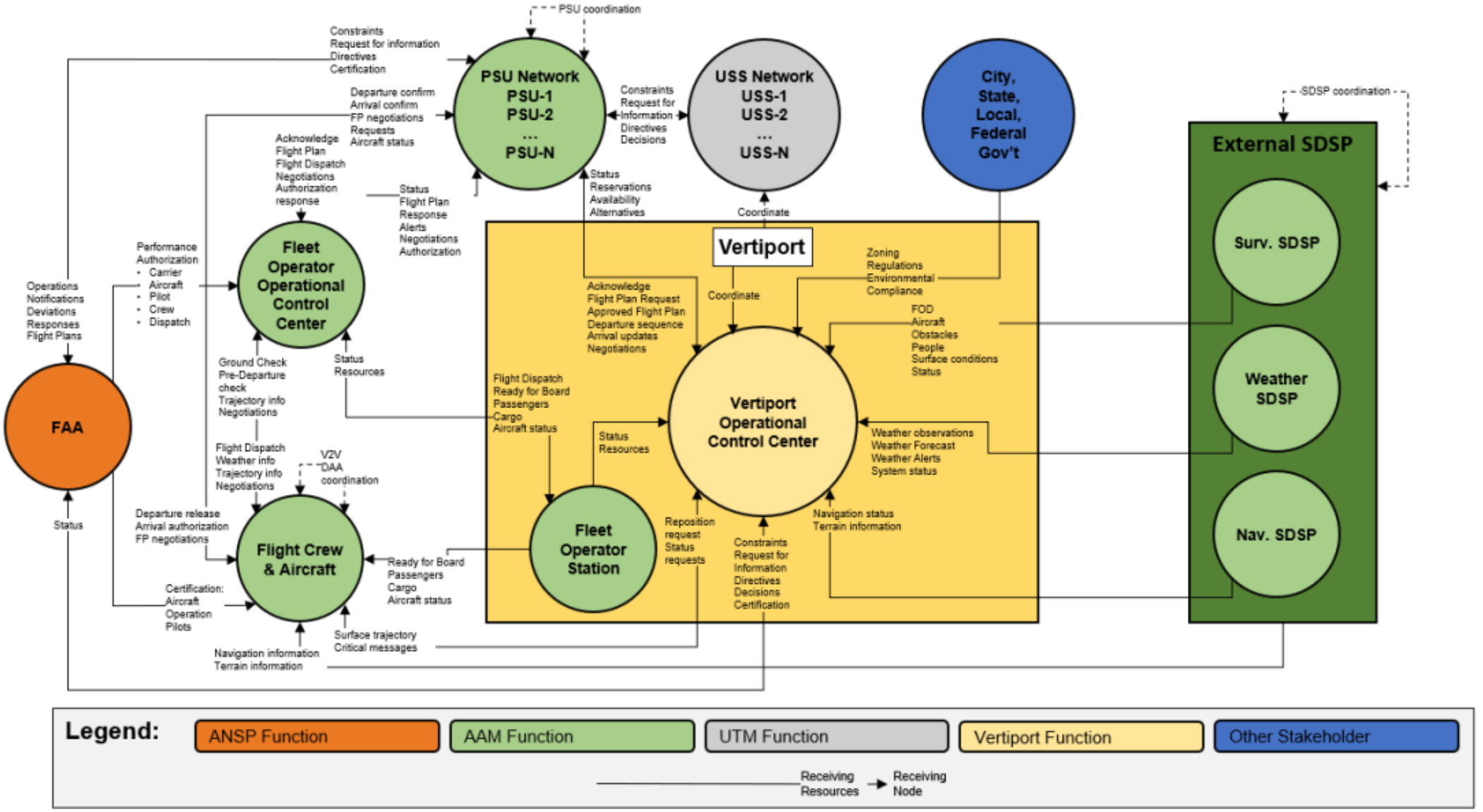


Figure 15: Vertiport Automation System (VAS) OV-2 Diagram

High Density Vertiport Operations Concept

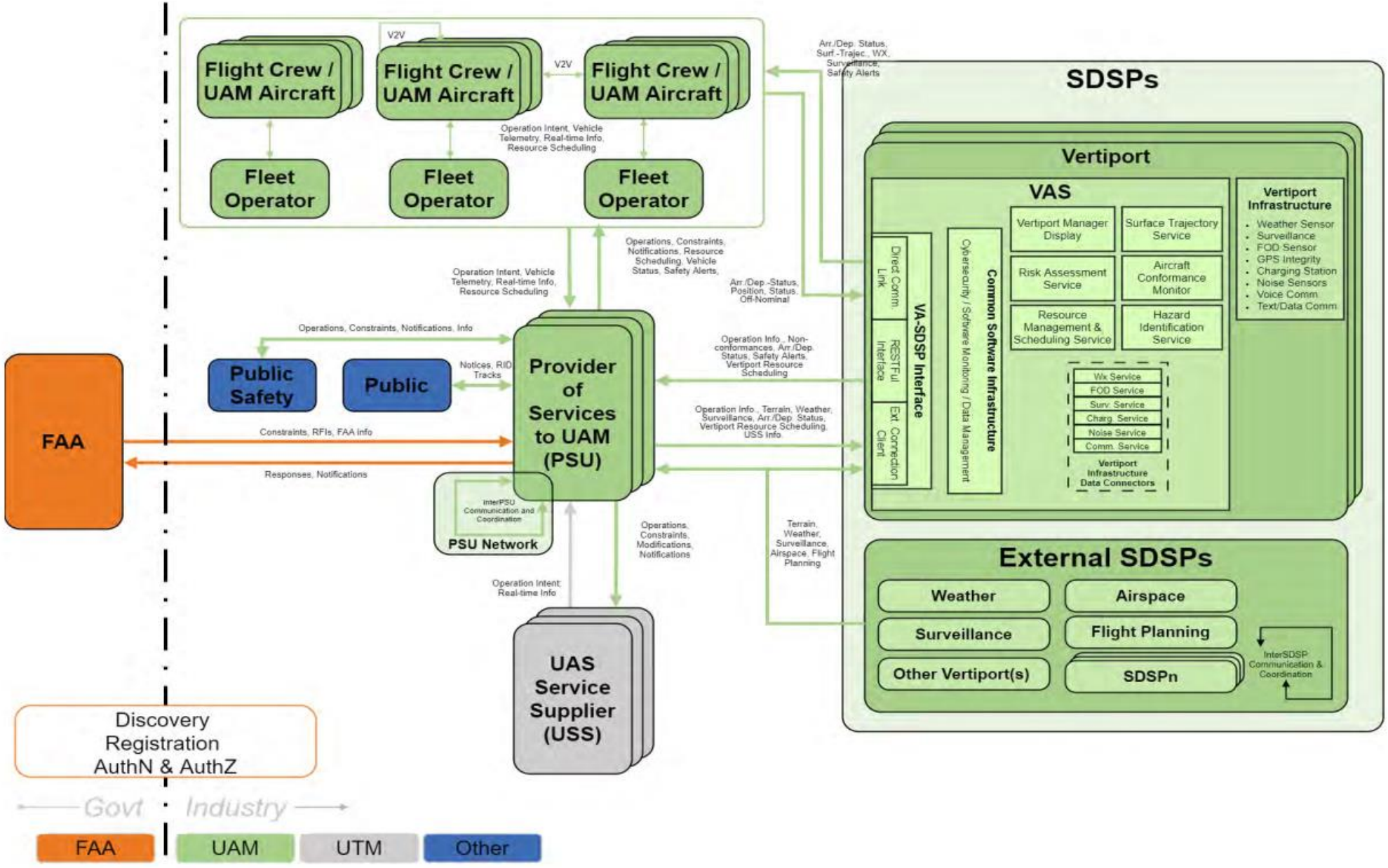


Figure 1. SvcV-1 Services Context Description

High Density Vertiport Operations Concept

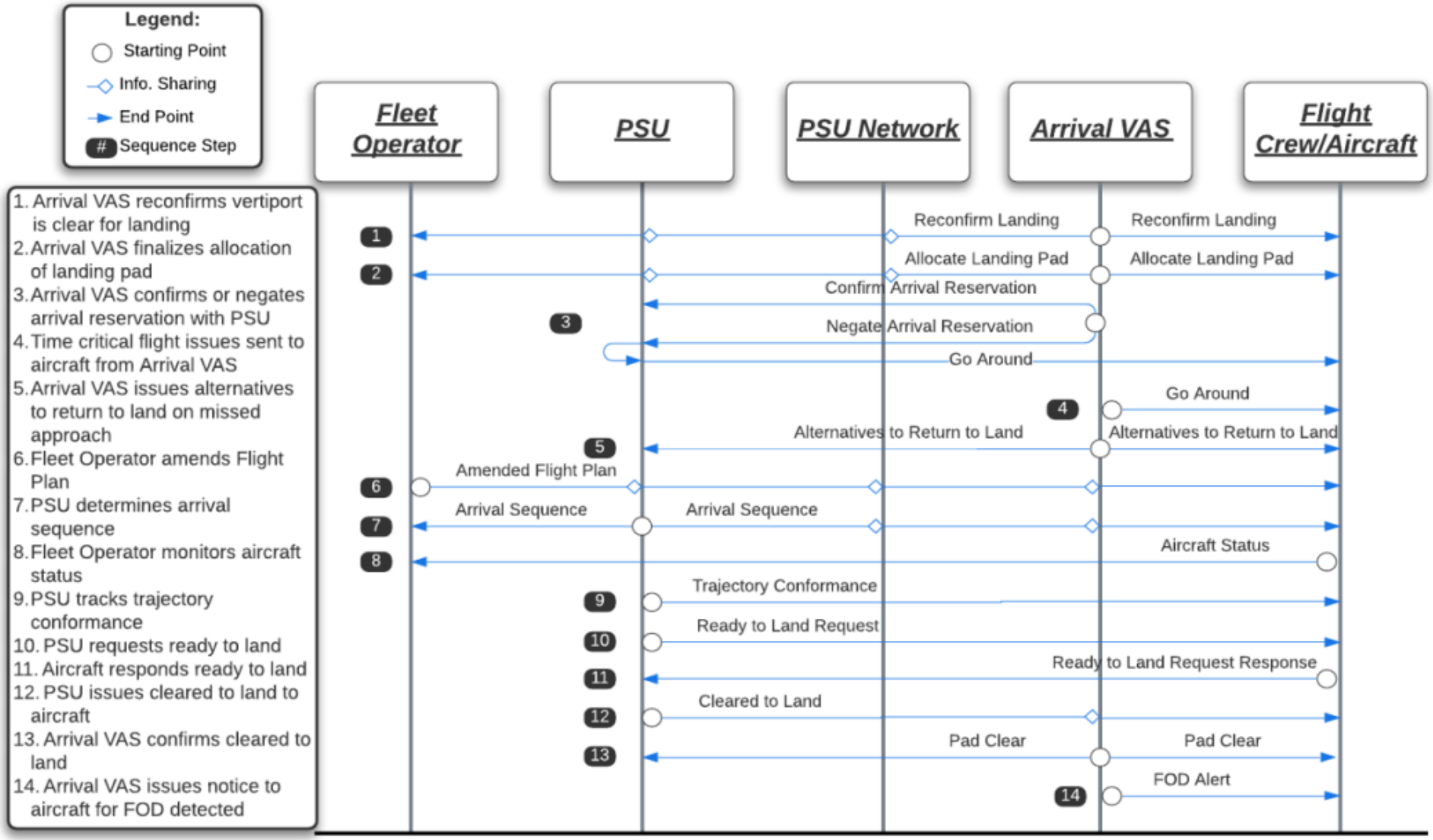
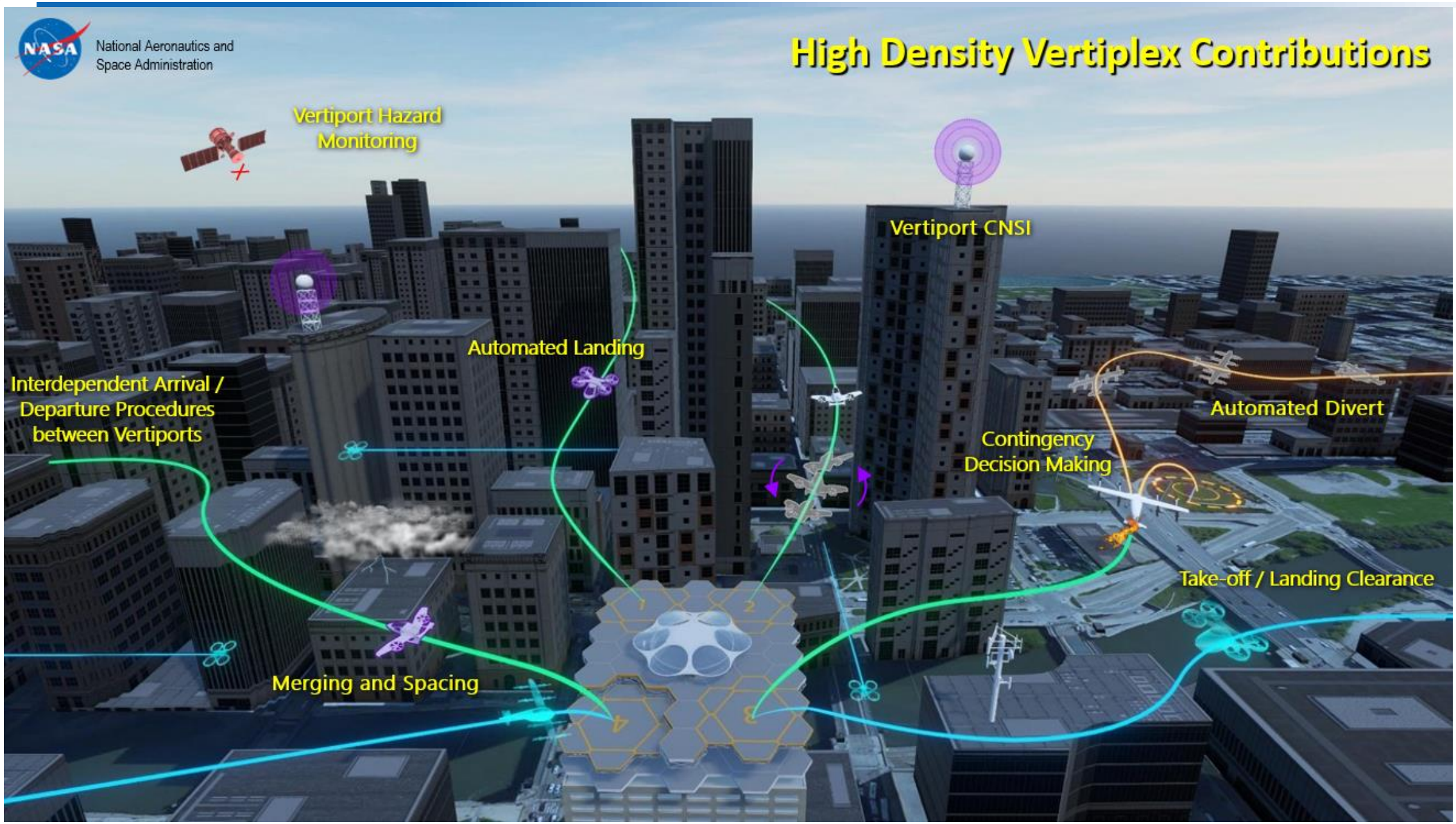
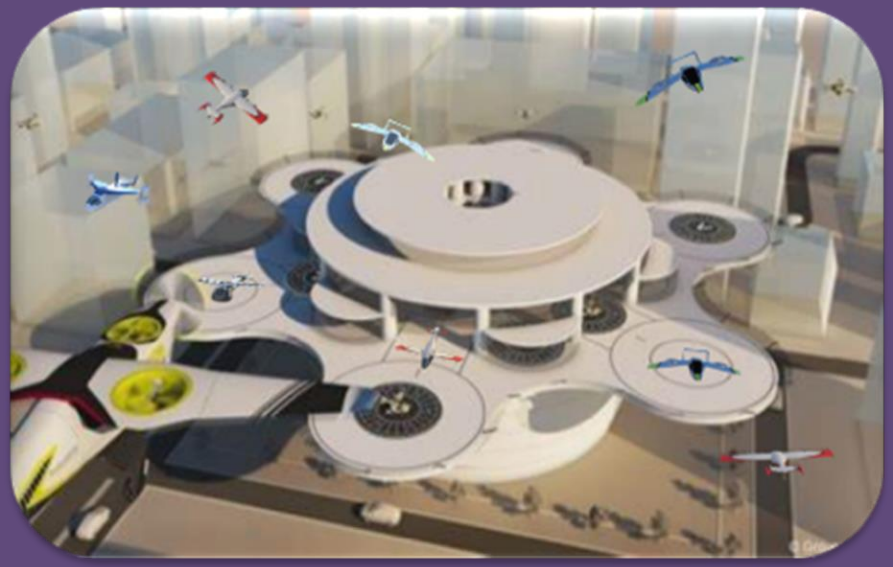


Figure 19: Approach Sequence Diagram

High Density Vertiplex Planned Contributions



High Density Vertiplex Research



Technical Challenge

Develop and evaluate a reference automation architecture that addresses scalable and efficient aircraft operations, flight and airspace management procedures, and vertiport operations in high density vertiplex environments.

Schedule Package Goals:

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- **Integration of Automated Systems 2 – HDV (IAS-2.HDV):** Develop and evaluate vertiport automation reference architecture for a representative UAM aircraft in a vertiplex environment.

HDV Research Flow to Key Deliverables

Key Deliverables

UAS Automation Reference Architecture (Vehicle Autonomy, Airspace Management, Fleet Management Autonomy)

Automated Aircraft

CY2022	CY2023	CY2024	IAS-2 / NC-2
Small UAS (3)	Small UAS (5)	Small UAS (7)	AAM eVTOL
Automated Landing	Merging and Spacing	Contingency Decision Making	

Operations

CY2022	CY2023	CY2024	IAS-2 / NC-2
Simulation and Multi-Aircraft VLOS Flight Test	Simulation and Limited BVLOS	Simulation and Expanded Operations (BVLOS & High Density Vertiplex ops)	Operational Environment

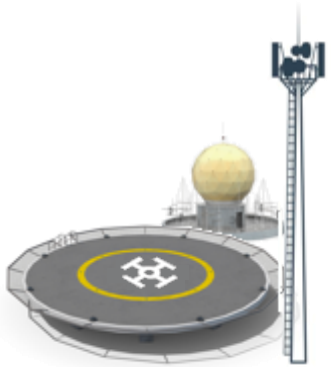
High Density Vertiport CONOPS

HDV Use Cases

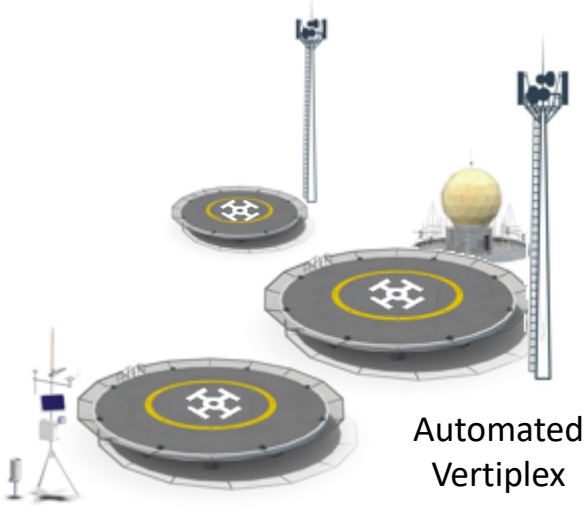
BVLOS Safety Case

Infrastructure

Vertiport Terminal Procedures Design



Instrumented and Connected Vertiport



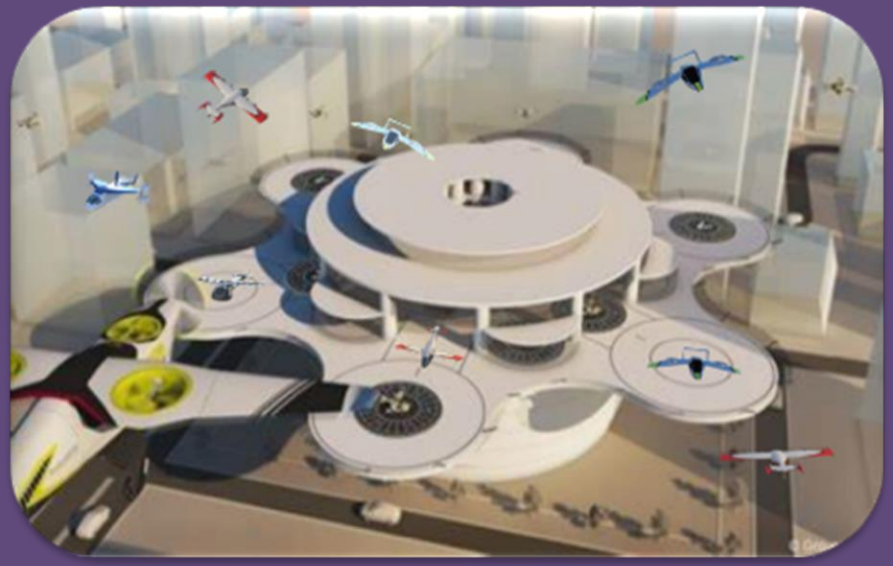
Automated Vertiplex

Vertiport Automation System and Reference Architecture & Requirements [MBSE]

HDV Research and Development Approach

- Each work package involves a progression from integrated simulation to flight test with significant build up and preliminary testing
- High levels of coordination required within and between teams across many disciplines
- Small UAS used as initial surrogate aircraft to test onboard automation systems, ecosystem integration, and scaled live operations
- Incremental build up of capabilities across scheduled work packages culminating in joint activities with broader integration with systems, infrastructure, and eVTOL aircraft

High Density Vertiplex Research: 2022



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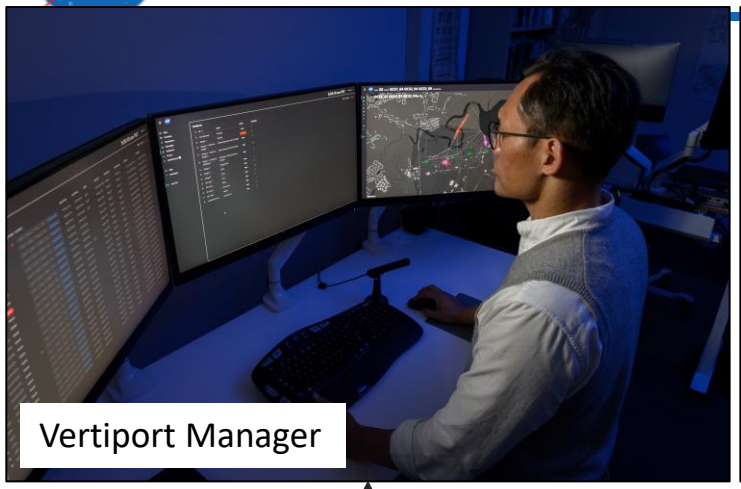
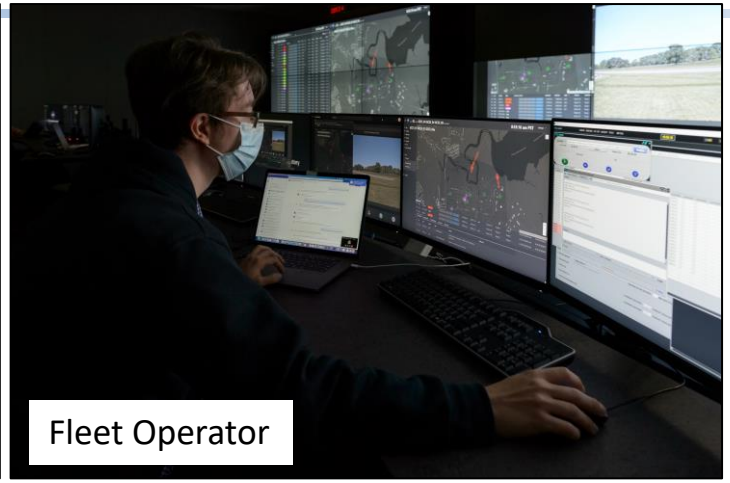
AOA Integrated Architecture Elements


Vertiport Manager

Fleet Manager


Fleet Operator

Vertiport Management Service

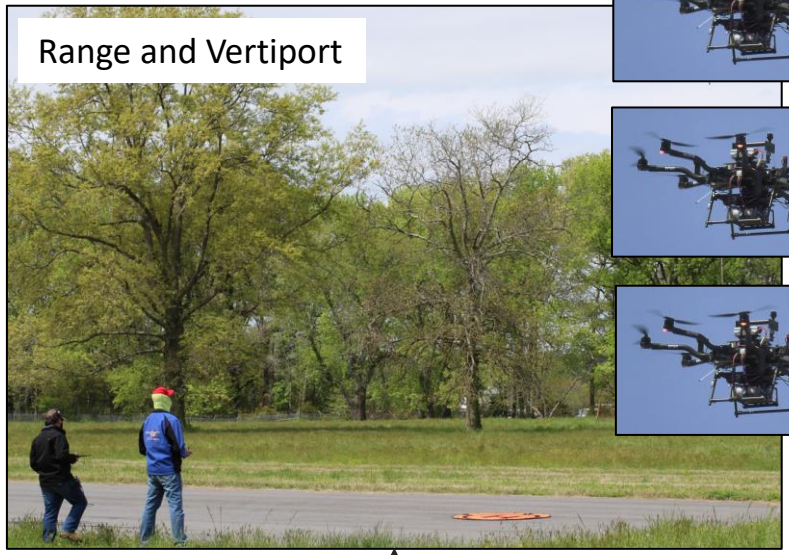
Airspace Services (PSU)

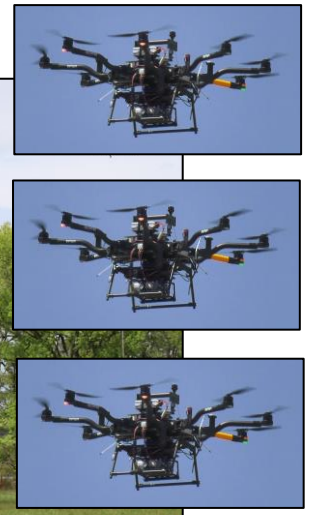
Fleet Management Service

Fleet Operations (sim)

Range Operations and Flight Center

Flight Crew


Range and Vertiport

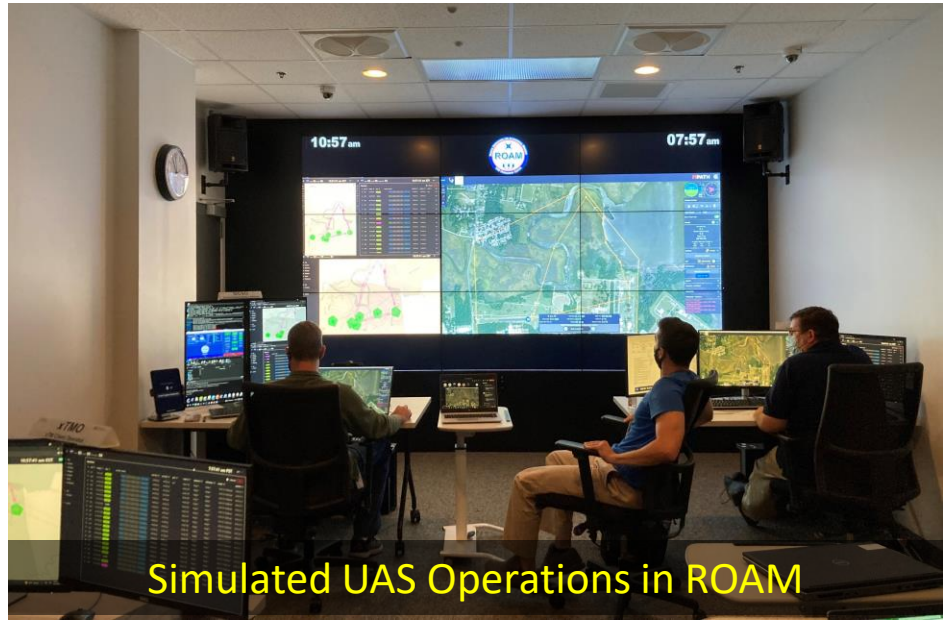

Vehicles and Onboard Automation

ARC

LaRC

Advanced Onboard Automation (AOA) Simulation Q1FY22

- **Objectives**
  - Perform UAM Ecosystem Prototype Assessment with simulated sUAS surrogate ownship aircraft
  - Use Human+Hardware In the Loop (HHITL) testing
  - Verify functionality of HDV UAS automation architecture to perform simulation testing and facilitate flight testing
  - Collect data to support BVLOS safety case for remote operations from the ROAM UAS Operations Center
  - Collaborate with TTT Human-Autonomy longitudinal study and SWS
- **AOA Simulation Stats**
  - Data collection: 9/30 to 10/13
  - 6 ground control station operators and 3 fleet managers test subjects
- **Outcomes**
  - Baseline system-in-test and scenarios for AOA Flight Test
  - Data collection to support long-term research questions
  - Results published in DASC 2022

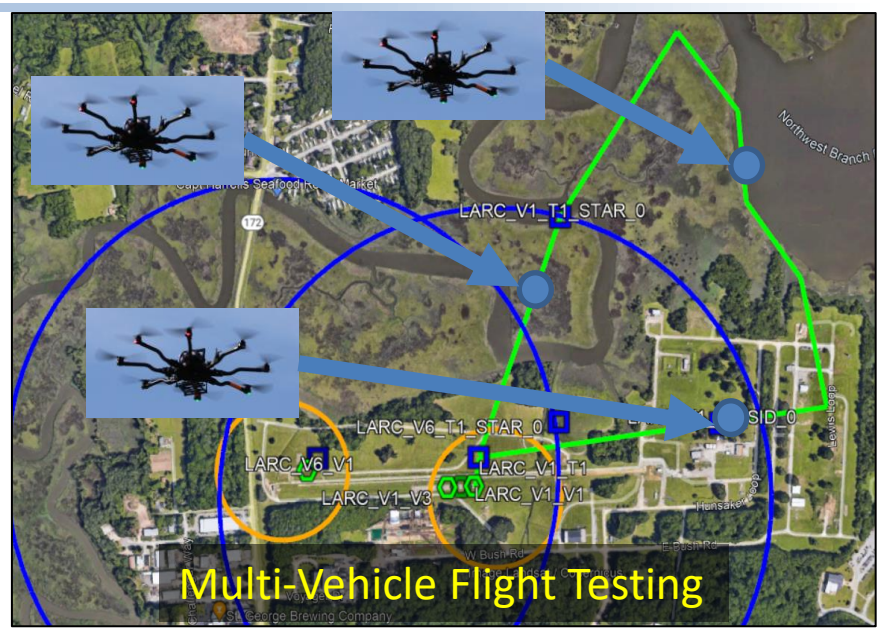


Simulated UAS Operations in ROAM

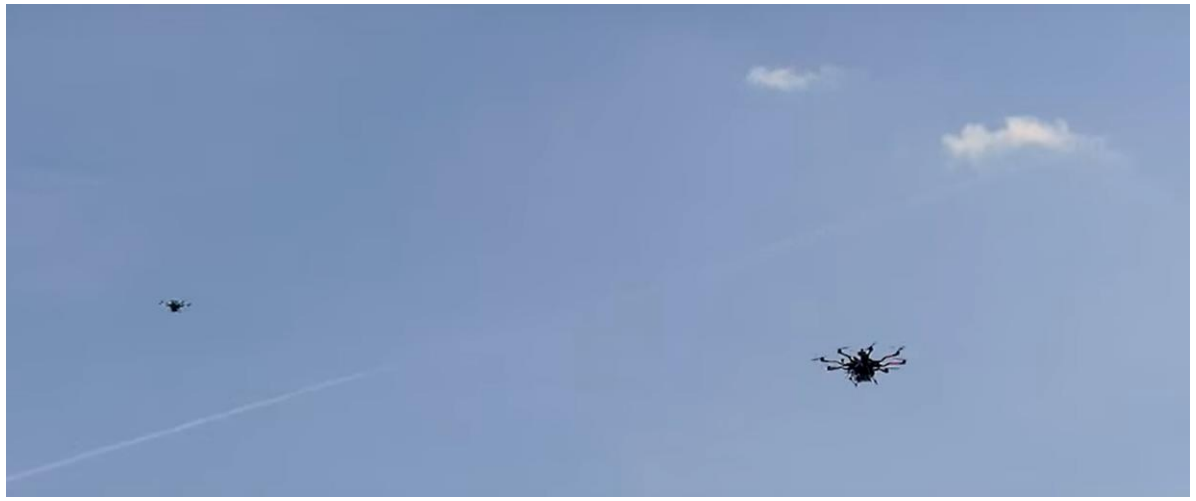
Simulated Fleet Manager Operations in AOL Lab

AOA Flight Test Q3 FY22

- **Objectives**
  - Perform UAM Ecosystem Prototype Assessment with live sUAS surrogate ownship aircraft
  - Complement and verify results from AOA Sim
  - Expand operational capabilities to support more complex research flight testing
- **Accomplishments**
  - Alta-8 aircraft configured with NASA Techs to represent UAM aircraft
  - Full integration with LaRC and ARC labs:
    - LaRC: ROAM, ARC: AOL, AVAL
  - Nominal and Off-Nominal Vertiport operations performed
    - Off-Nominal included: Vertiport Closures and Emergency Vehicle ops
  - Human Factors results acquired for Ground Control Station Operators, Fleet Managers
  - Max of three vehicles operated in EVLOS ops
- **Outlook**
  - Results leveraged to enable Scalable Autonomous Operations Schedule Work Package (SWP)



AOA Flight Test



Days of Flight

10

Number of Flights

54

Single Vehicle Ops

13

Dual Vehicle Ops

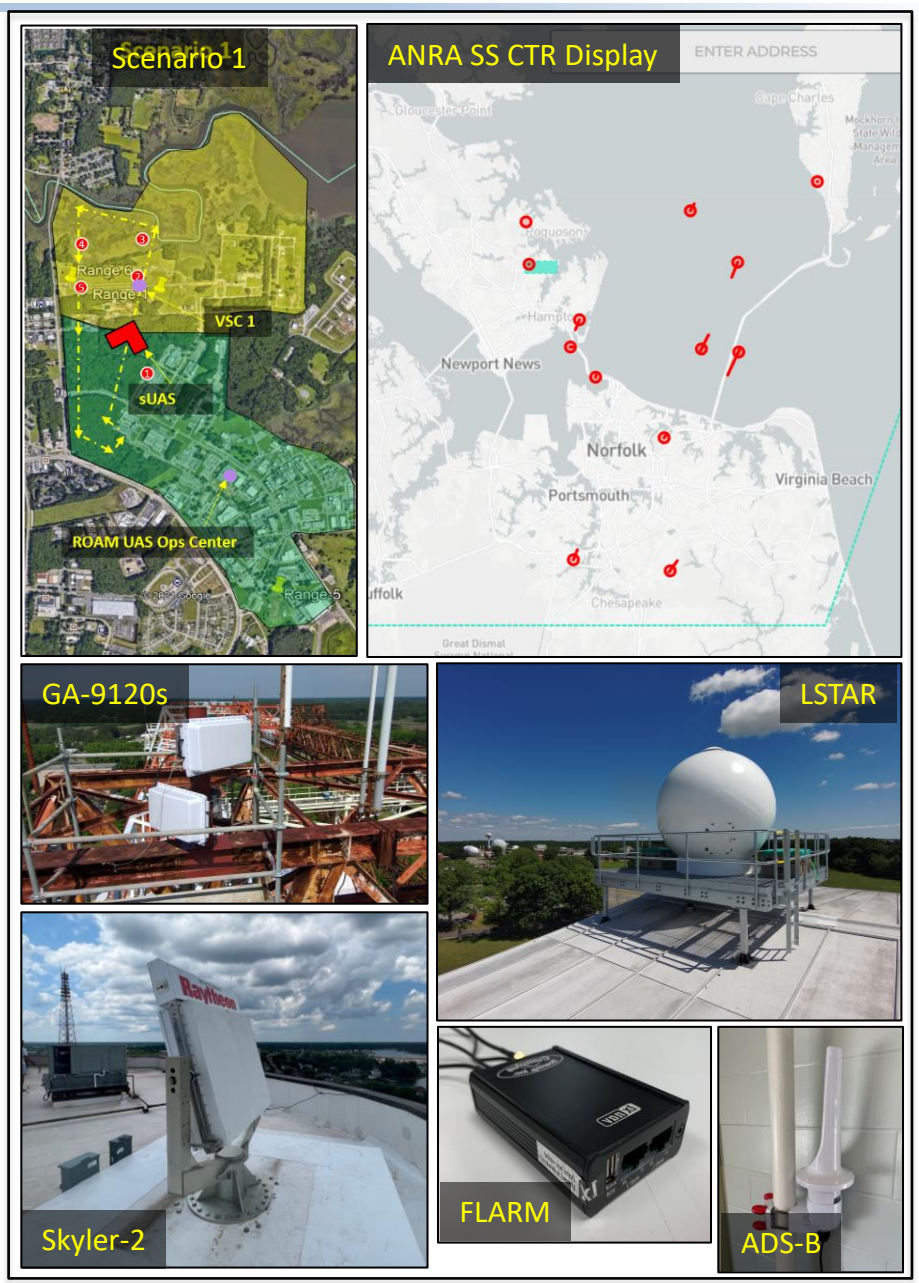
29

Triple Vehicle Ops

12

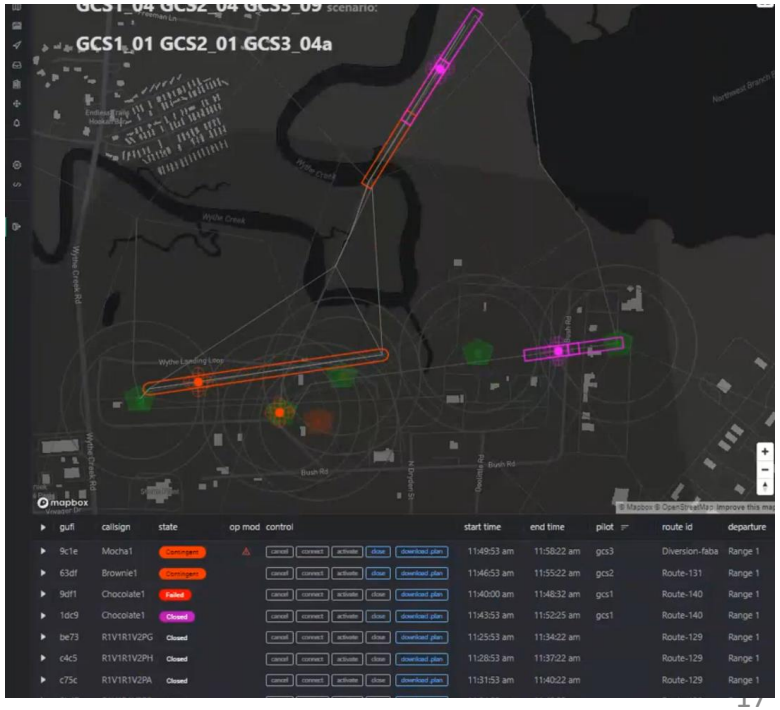
HDV Infrastructure Initial Capability FY-23

- HDV AOA Flt Test completed in April, 2022
  - Extended Visual Line of Sight (EVLOS) operations within yellow areas
  - Ground Control Station Operators (GCSOs) can't see aircraft or airspace
  - Green areas can be Extended or Beyond Visual Line of Sight (E or BVLOS)
- HDV is installing ground-based surveillance systems
  - LSTAR and GA-9120s radars, ADS-B, FLARM
  - Access to Skyler radar through SAA
  - ANRA Smart Skies Control system used to integrate and display surveillance information and route radar data to sUAS
- NASA Technologies provide operational credit:
  - ICAROUS: Autonomous Detect and Avoid
  - Safe2Ditch: Autonomous Contingency Management
- Crawl->Walk->Run
  - Build upon AOA Flt success
  - Fly expanded EVLOS operations through Scalable Autonomous Operations (SAO) flight test
    - Produce verification test data to support Safety Case
    - V1 submitted to FAA 10/7
  - Transition to longer flights when able (ie remove VOs) Q4FY-23



Knowledge Gained in AOA Testing

- Advanced NASA HHITL Sim capabilities
  - Provided excellent initial results regarding UAM Ecosystem Prototype Assessments
  - Greatly facilitated subsequent flight test efforts
- Extended Visual Line of Sight Operations
  - Provides stepping-stone towards BVLOS ops
  - Results representative for UML-4 UAM Ecosystem
    - GCSO/FM/VM/PSU/Representative Automated Aircraft
- Initial evaluation of UAM Ecosystem completed
  - Initial HHITL sim and flight testing completed for low-density traffic
  - UAM-adapted FM trial-planner evaluated
    - Considered to be sufficient for conditions tested
    - More development/testing required
  - Onboard DAA systems can ensure well clear and complement FM
  - Autonomous contingency management system provided effective off-nominal vehicle management
- Established environment for Vertiport Automation System development and testing



HHITL: Human+Hardware-In-The-Loop, GCSO: Ground Control Station Operator, FM: Fleet Manager, Vertiport Manager, PSU: Provider of Services UAM

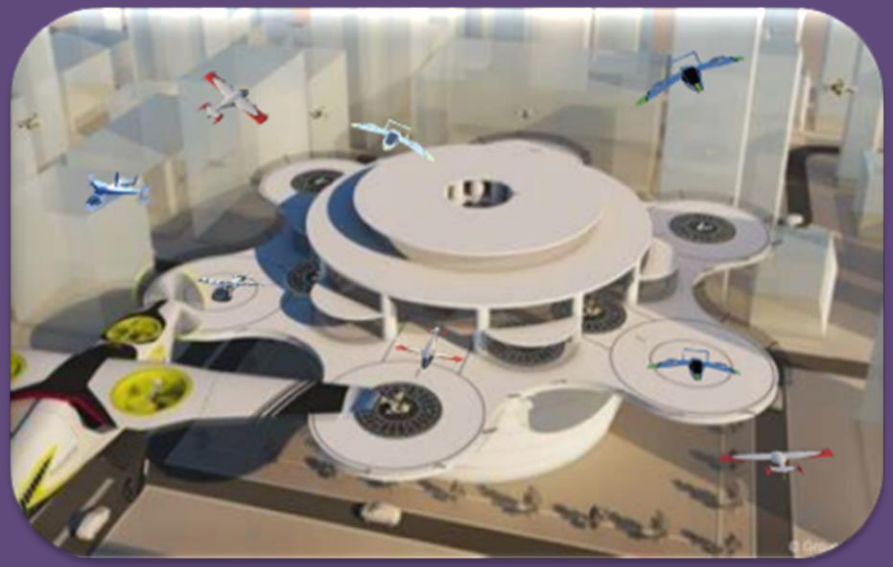
AOA Takeaways

- Successful completion of the AOA work package through simulation and flight testing represented the most comprehensive, distributed AAM ecosystem implemented, staffed, and tested to date
- AOA flight testing was very successful in establishing the use of small UAS (sUAS) for surrogate testing of onboard automation and flight crew procedures in HDV. Additional work is needed to align vehicle approach and departure procedures to follow with those being developed across the AAM Project.
- For greater control and management of planned vertiport operations, additional capabilities are needed at the vertiports to support envisioned vertiport manager roles and the supporting services in development
- The limited number of live flights limited the potential interactions and flexibility between the fleet manager and fleet operators. Greater interactivity between the fleet manager and fleet operators (to include the vehicles) was determined to be highly desirable and planned for the subsequent work packages.
- Fleet and vertiport management capabilities were implemented for the first time in AOA. As these are new roles to be explored in an AAM environment, it was clear that the performance of these roles and their integration in HDV testing will benefit from focused Human Factors evaluations and participation from individuals with relevant backgrounds and experience.

HDV AOA Information Dissemination

- Advanced Air Mobility (Aam) Vertiport Automation Trade Study: https://ntrs.nasa.gov/citations/20210009757
- High-Density Automated Vertiport Concept Of Operations: https://ntrs.nasa.gov/citations/20210016168
- Vertiport Automation Software Architecture And Requirements: https://ntrs.nasa.gov/citations/20210019083
- DASC 2022 Publications:
  1. Glaab, L: *The High Density Vertiplex Advanced Onboard Automation Overview*
  2. Unverricht, J: *Eye Glance Behaviors of Ground Control Station Operators in a Simulated Urban Air Mobility Environment (TTT Collaboration)*
  3. Suzuki, A: *A Flight Replanning Tool for Terminal Area Urban Air Mobility Operations*
  4. Gaug, N: *Lightweight Surveillance and Target Acquisition Radar Characterization for High Density Vertiplex Beyond Visual Line of Sight Operations*
  5. Hoddel, G: *Usability Evaluation of Fleet Management Interface for High Density Vertiplex Environments*
- AOA Flight Test report NASA TM (R. McSwain): *https://ntrs.nasa.gov/api/citations/20220016890/downloads/NASA-TM-20220016890.pdf*
- NASA Feature Content: https://www.nasa.gov/feature/nasa-vertiport-research-takes-flight
- NASA Web/Video Feature: https://www.youtube.com/watch?v=jg3FCuARUGs

High Density Vertiplex Research



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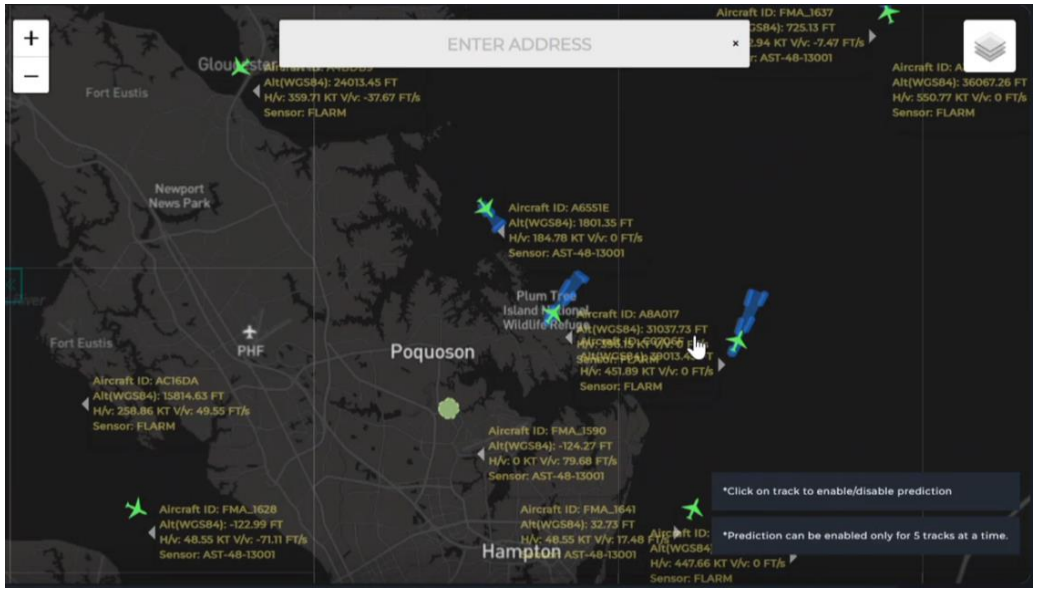
HDV Status in 2023

- 2023 will be primarily dedicated to execution of the Scalable Autonomous Operations (SAO) schedule work package
- Major developments will include:
  - Introduction of a Vertiport Automation System
  - Vertiport sensor and area surveillance system integration
  - Vertiport Manager participant role and supporting displays
  - Increased traffic density (60 movements/hour) and route diversity
  - Missed Approach procedures and scenarios
  - Integrated operations with Flight Crews, Vertiport Manager, Fleet Manager, Multi-Vehicle Supervisor, and live vehicles exchanging data in real time
- These developments will be tested through large-scale, distributed simulation, flight testing, and dedicated efforts to enable long-range operations

Wide Area Hazard Locator for Drone Overflight (WAHLDO)

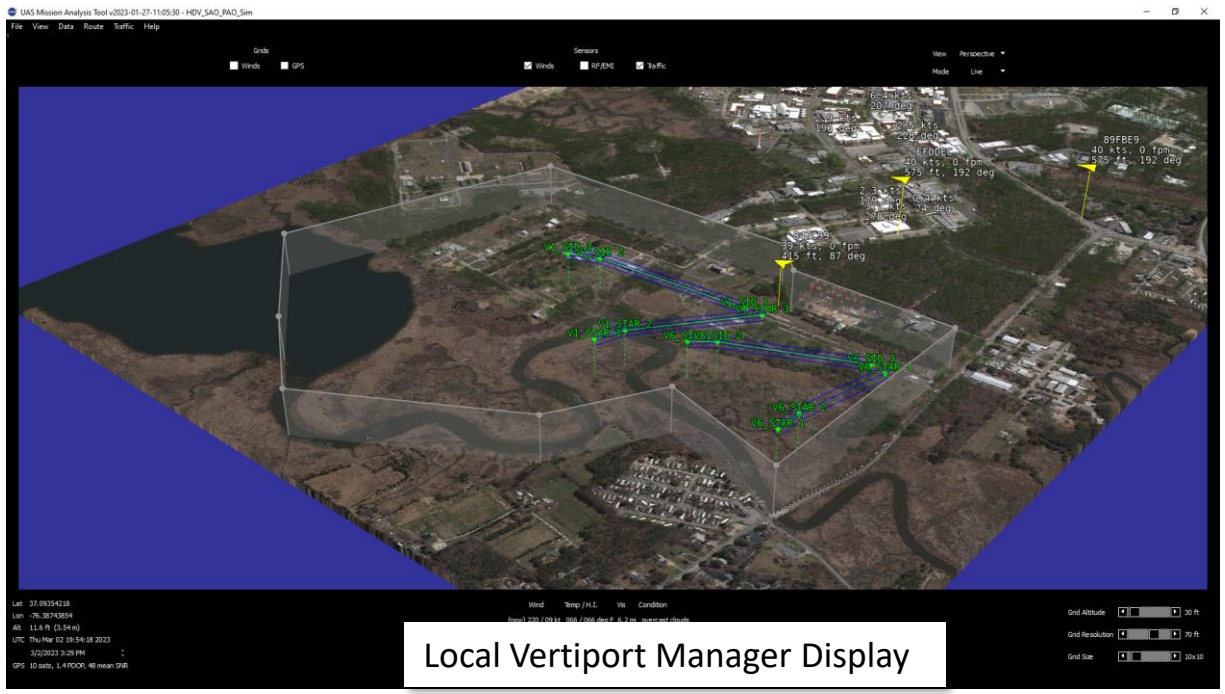
ANRA Smart Skies Data Fusion



SAO Simulation Progress

- ARC and LaRC teams began SAO simulation on March 1st , 2023
- Vertiport Automation System integrated into HDV ecosystem with associated displays, Vertiport Manager position, and message exchanges
- Flight testing planned early summer

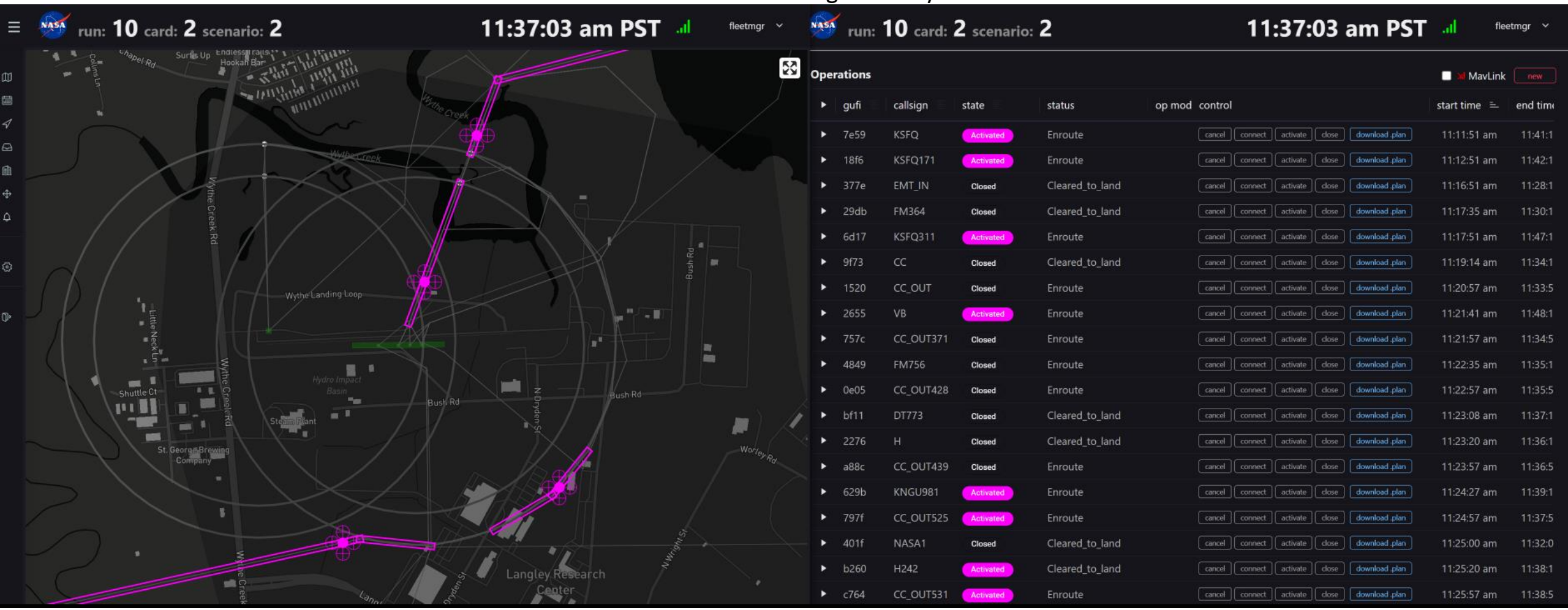
Remote Ops for Autonomous Missions: NASA Langley Research Center



Local Vertiport Manager Display

Sample Refinements in SAO

HDV Fleet Management System



- Updated procedures and adaptations added
  - Vertiport airspace structures (VPV and VOA)
  - Initial and Final Approach Fixes
  - Wheel approaches and departures
- Flight phase tracking and updating
- VAS data exchanges for landing approvals at thresholds
- VAS schedule and Vertiport Manager controls
- Missed Approach/Divert procedures w/ trial plan support

Questions?

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